11.—Stratigraphy of the Boogardie Group

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The Boogardie Group at Mount Magnet, Western Australia forms part of a succession of Archean rocks known as the "Older Greenstones." The group overlies the Lennonville Beds and other older rocks and is overlain by an unknown thickness of sedimentary and igneous rock. It has developed minerals typical of the greenschist facies of metamorphism.

Nine formations make up the group. These are in ascending order: Poverty Flat Formation, Jupiter Jaspilite, Mount Magnet Greenstone, Three Boys Formation, Perseverance Jaspilite, Mars Greenstone, Hill 50 Jaspilite, Havelock Greenstone and Saturn Formation. Within these formations fine-grained sediments, volcanic rock and jaspilite are conformably interbedded. They were probably deposited within an eugeosyncline which itself provided a source for clastic and chemical material. Instability during deposition has caused: buried valley structure; buried hill structure; rapid thickening of units; slump structures and brecciation. Ripple marking and cross lamination in siltstone and calcareous nodules in jaspilite were used to determine sequence.

During intrusion of granite the group was folded, metamorphosed and fractured. The intrusion of porphyry and quartz blows followed and was accompanied by mineralization. Later, during taphrogenesis, dolerite was intruded.

Erosion has since peneplaned the area. There is evidence of a more rugged topography before lateritization in the Tertiary.

Introduction

Boogardie is situated approximately 3 miles N. 65° W. from Mount Magnet and approximately 300 miles NNW. of Perth, Western Australia. Gold-bearing ore is being produced at the present time (1958) from two mines at Boogardie. These are the Hill 50 and Hill 50 Eclipse gold mines. To the end of 1956 the Hill 50 gold mine had crushed 982,105.90 tons for a return of 448,601.75 fine ounces of gold.

The Archean rocks of the district are steeply dipping and consist of lavas, sedimentary greenstones and jaspilites, probably deposited in an eugeosyncline. A stratigraphic subdivision of these rocks has been made and their proposed nomenclature is set out herein.

General Stratigraphy

The interbedded lavas and sediments of the Mount Magnet district are tightly folded and intruded by granite. They fall within the Yilgarn Geosyncline of Prider (1952) and are consequently correlated with the Older Greenstone Phase of Prider (1948).

The distribution of rocks near Boogardie is shown in Fig. 1. Two major stratigraphic units have been delineated—the Lennonville Beds and the Boogardie Group.

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The Lennonville Beds

The name Lennonville Beds is proposed herein for the sequence of greenstones, jaspilites, cherts and (?) conglomeratic quartzites, of Precambrian age, bounded above by the Boogardie Group and below by an unknown thickness of sediments.

The Lennonville Beds to the north of the Hill 50 gold mine are composed in stratigraphic order of the following lithologies:

4. 2,500-7,500 feet of amphibolite, chloritized quartz dolerite and chlorite schist, with thin (6 ins.-1 foot) jaspilite beds.
3. 45 feet ± of quartzite, conglomerate, and conglomeratic quartzite.
2. 50 feet ± of chert.
1. 90 feet ± of interbedded greenstone and jaspilite with thin cherty members, grading in the upper 30 feet to jaspilite with rare cherty members.

The jaspilites and cherts are coarser in grain size than those nearer Boogardie. Stylolitic seams parallel the bedding in the cherts, and adjacent to the seams recrystallization is marked. Lateral gradation of interbedded chert and jaspilite is best explained by a sedimentary facies change for the following reasons:—

There is no apparent change in thickness when jaspilite changes to chert; there is rapid change in iron content and close association of jaspilite with chert; stylolites in banded iron formations generally mark an increase in iron content, not a complete absence of this element.

The stratigraphic position of the quartzite, (?) conglomeratic quartzite and (?) conglomerate is in doubt, but it is thought that they are a conformable sedimentary sequence within the Lennonville Beds. They vary lithologically from conglomeratic quartzite to even-grained quartzite. Under the microscope these rocks show little evidence of the fragmental texture seen in hand-specimen. Large fragments in the conglomerate or breccia are similar to the matrix, being distinguished from it only by a lack of ferruginous cement. Bedding and the recrystallized nature of the rock suggest it is conformable with the jaspilites. However, some specimens resemble the superficial deposits known elsewhere in Western Australia as "billy."

It may be considered that the conglomeratic quartzite and even-grained quartzites are conformable with the jaspilites and that a superficial deposit was formed on these rocks in comparatively recent times. This explanation is accepted until the problem of the two rock types of roughly similar composition but different metamorphic grade can be solved.

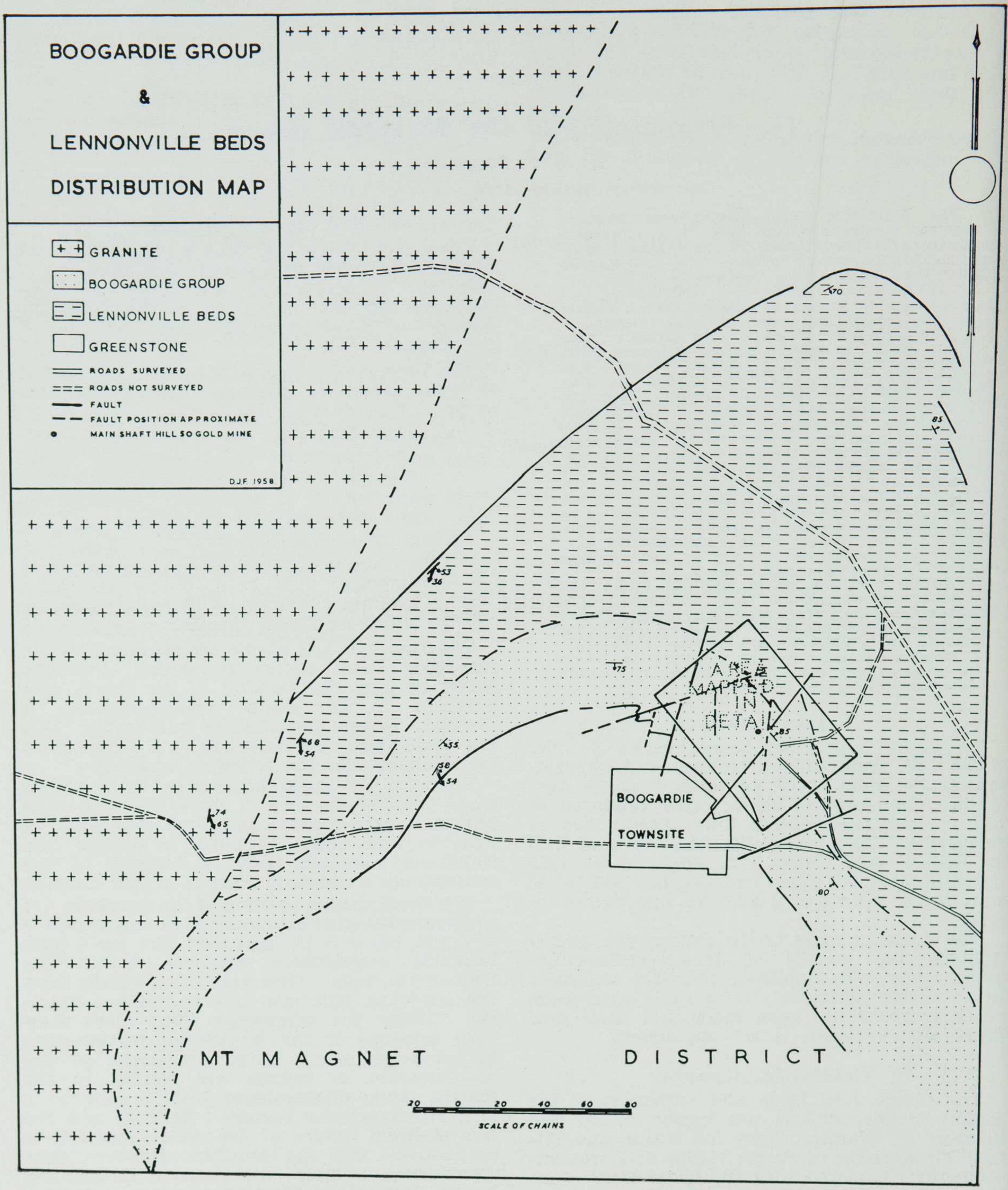

Fig. 1.—Distribution map (compiled from aerial photographs and traverses on foot).

Chert, jaspilite and quartzite are the basal rocks of the Lennonville Beds; above the base there is a considerable thickness of greenstone, with minor jaspilite beds. The greenstone is dominantly amphibolite and chloritized quartz dolerite in fresh outcrop. Closer to the Boogardie Group the greenstones are highly weathered schists.

The Boogardie Group

The name Boogardie Group is proposed herein for part of the sequence of sedimentary and conformable igneous rocks in the south-plunging syncline about Boogardie. The group has been traced in outcrop from two miles south-east of the Hill 50 gold mine, through the trough of the fold (adjacent to the Hill 50 gold mine), to a point four miles south-west of Hill 50 where the sediments abut against the granite. The strata which dip steeply have an average thickness of 4,000 feet.

The formations within the Boogardie Group are presumed to be Archean in age. The following is a summary of the sequence (Fig. 2).

Boogardie Group.—Jaspilites and greenstones of Archean age conformably contained in the greenstones of the Mount Magnet district and composed of the following nine formations, in stratigraphic order:—

9. Saturn Formation.—A sequence of jaspilites and greenstones including bedded sericite-carbonate-quartz-chlorite schist. Thickness 702 feet ±.

8. Havelock Greenstone.—Fine-grained chloritized quartz dolerite underlying a six-inch jaspilite member. Thickness 17-40 feet.

7. Hill 50 Jaspilite.—Jaspilite. Thickness, (?) 50-80 feet.

6. Mars Greenstone.—A sequence of jaspilites and greenstones including bedded magnetite-bearing biotite-quartz-chlorite schist, chloritized quartz dolerite and plagioclase-quartz-carbonate-chlorite rock. Thickness, 140-280 feet.

5. Perseverance Jaspilite.—Jaspilite with calcitic nodules. Thickness, 20-38 feet.

4. Three Boys Formation.—Jaspilites and greenstones including sericite-quartz-magnetite-carbonate-chlorite schist and plagioclase-bearing sericite-magnetite-carbonate-quartz-chlorite rock. Thickness, 250-330 feet.

3. Mount Magnet Greenstone.—A sequence of minor jaspilites and greenstones including banded magnetite-plagioclase-carbonate-chlorite rock and quartz-carbonate-sericite-chlorite rock. Thickness, 300-710 feet.

2. Jupiter Jaspilite.—Dominantly jaspilite carrying calcitic nodules, and interbedded with greenstone lenses. Thickness, 4-30 + feet.

1. Poverty Flat Formation.—Dominantly magnetite-quartz-carbonate-chlorite schist with minor magnetite-sericite-quartz-chlorite schist and characterized by four or five interbedded 6 in. to 1 ft thick jaspilite members. Thickness, 1,033 ± feet.

Intrusive into the Lennonville Beds and the Boogardie Group are various quartz-feldspar porphyries, granite, quartz blows and dolerite, which will be dealt with below.

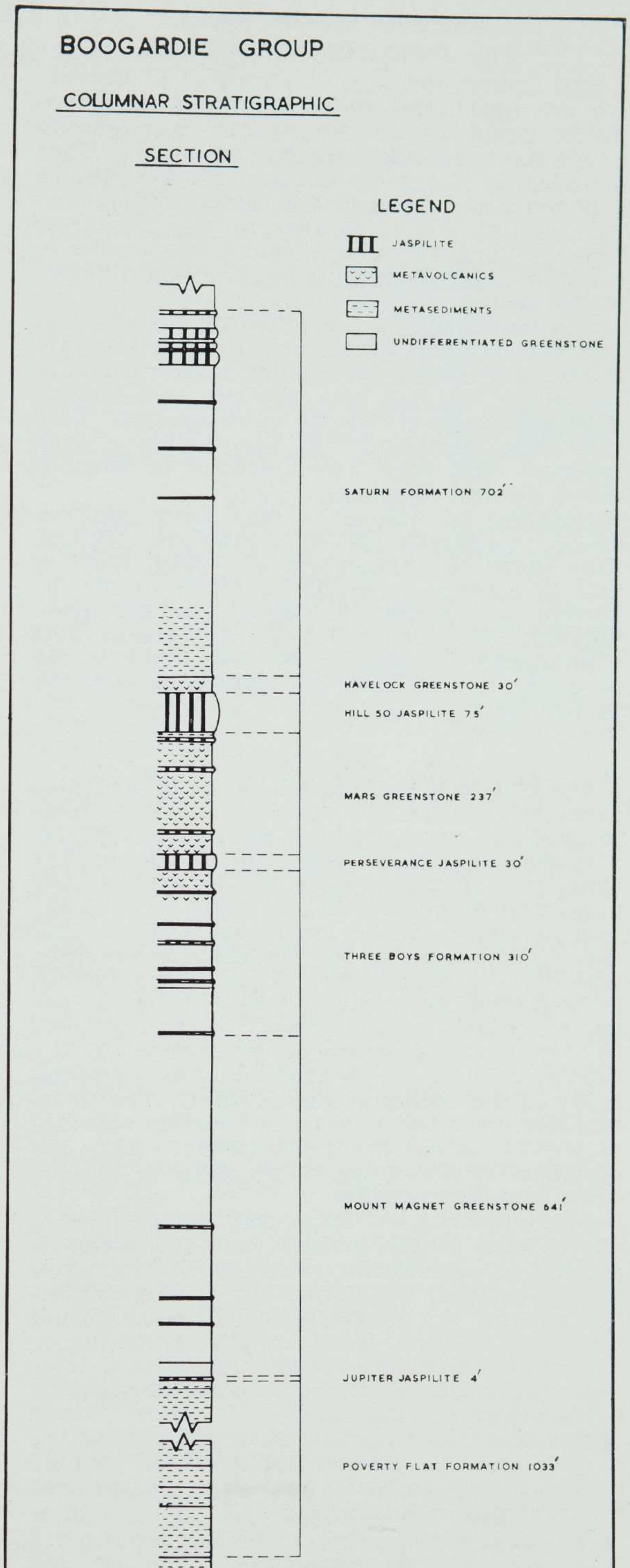

Fig. 2.

Intrusive Igneous Rocks

The Porphyritic Dyke Rocks

The "porphyries and porphyrites" of Boogardie are hypabyssal rocks ranging from leucodacite porphyry to porphyritic micro-diorite (andesite) and micro-diorite (andesite). They intrude the Boogardie Group near the Hill 50 gold mine and trend in two general directions: 30° east of north, parallel to the Boogardie "Breaks," and 50° west of north, subparallel to the strike of the sediments and the "Main Fault" of the Hill 50 gold mine.

The porphyrites are dominantly post-folding, and post-faulting intrusives, although they are displaced by minor flat-dipping reverse faults in the mine, and are also sheared and jointed. Flow alignment of chlorite pseudomorphs (possibly after hornblende) in one porphyrite dyke indicates that they were intruded in what is now a vertical direction.

Intrusion of porphyrite may have occurred over a considerable period, as Finucane (1953, p. 232) shows the "Main Fault" (which itself is said to contain a porphyrite filling in places) cutting the porphyrite filling the Boogardie "Breaks." Finucane (1953, p. 232) claims that a little gold has occasionally been found in the porphyry, so that they are tentatively regarded as pre-ore.

Granite

The granite varies between a fine- to medium-, even-grained gneissic adamellite and a fine- to medium-, even-grained massive adamellite. The igneous contact with amphibolites on the west limb of the syncline is well-exposed two miles west of the Hill 50 gold mine. The lineation developed in the amphibolites is identical with that in some of the amphibolitic xenoliths within the granite itself. There are numerous cross-cutting aplogranite dykes in the greenstone adjacent to the contact. In these a foliation is developed which is not parallel to the dyke trend itself but is subparallel to the schistosity of the enclosing amphibolites. The foliation developed in the granite, trending approximately 20°, is parallel to the contact and to the direction of elongation of xenoliths of amphibolite and metajaspilite.

The similarity of structural features noted above, both in the granites and the adjacent amphibolitic schists indicates that the intrusion of the granite, the formation of the amphibolites, and the development of the lineation and the foliation were broadly synchronous. Therefore, the writer believes the regional folding was caused by, and took place during, the period of granite intrusion.

The absence of hornblende xenocrysts in the granite and the lack of feldspathized amphibolitic schists indicate that the granite was magmatically emplaced.

Quartz Blows

Quartz blows concordantly and discordantly intrude the schists and gneissic granite of the Mount Magnet district.

The quartz "reefs" are usually poorly mineralized. Gold, pyrite, stibnite, cervantite, stibiconite, scheelite, psilomelane, pyrolusite and fuchsite were noted by Jutson many years ago and tourmaline occurs in many of them. They are apparently lenticular, rarely greater than 10-15 feet wide, and some may be traced for several hundreds of feet along their strike. In the Boogardie district they are rarely longer than 20-30 feet.

Dolerite

A quartz dolerite dyke intrudes the Boogardie Group at the Hill 50 gold mine. The dyke has an east-west trend and maintains a constant width of 18 in. to 2 feet.

The absence of alteration in this rock, which intrudes chloritic schists, chloritized quartz dolerite and most probably partially altered porphyrite dykes, indicates that it is later in age than any of them and the lack of alteration and the inclusion of a xenolith of pyrrhotized jaspilite, demonstrates that the dolerite is post-ore in age. Structurally, it follows a trend foreign to the normal mine structures.

Metamorphism

The "greenstones" in the vicinity of the Hill 50 gold mine have developed minerals typical of the greenschist facies of metamorphism. Two and a half miles west-north-west of the mine the "greenstones" are intruded by granite and their mineral content is more typical of the albite-epidote or lower amphibolite facies of metamorphism.

Amphibole has been proven to develop in rocks originally of igneous character and also in rocks originally of sedimentary character without evidence of directional stresses. The resultant amphibolites are probably metasomatic in origin and occur in areas of low grade metamorphism as well as in areas of moderate grade metamorphism.

Superficial Deposits

Superficial deposits of conglomerate, travertine, laterite and alluvium are the products of weathering and erosion of the older rocks of the region.

Stratigraphy of the Boogardie Group

Within this section will be found the definition, facies variations, geographic distribution and petrography of the formations of the Boogardie Group. The petrography is limited to the component greenstones. The jaspilites show little variation and their petrographic description will be found in the following section under Petrology.

The Boogardie Group (Fig. 2) consists of nine formations with the following bottom-to-top sequence:—

Poverty Flat Formation

Poverty Flat is the name of an area approximately two miles south-east of the Hill 50 gold mine, and characterized by a number of thin jaspilite bars along which fault intersections have yielded occasional bonanzas.

Definition.—The Poverty Flat Formation is defined as that sequence of minor jaspilite bars and chert-carbonate-chlorite schists, which lies between and is bounded by the Lennonville Beds and the Jupiter Jaspilite.

TABLE I

Facies variations in the Jupiter Jaspilite

G.M.L. 1505M	G.M.L. 1361M	G.M.L. 1389M and 1478M	G.M.L. 1480 (a)	G.M.L. 1480 (b)
South end of area mapped			North end of area mapped	
			South-east corner	Centre
4′ jaspilite with nodules	4′ jaspilite with nodules	3′–4′ jaspilite with nodules	10′ jaspilite with two minor greenstone lenses 6″ to 1′ thick	6′ jaspilite with nodules 15′ greenstone 2′ 6″ jaspilite with nodules 9′ greenstone 18″ jaspilite with nodules

The formation is typically developed east-south-east of the Hill 50 gold mine between surface co-ordinates* 13660E 11100N and 12524E 11230N.

The type locality contains no unweathered outcrop. The extent of faulting could not be determined to fine limits and hence the thickness given is approximate only (assuming dips close to vertical).

Unweathered samples of the formation from the Jupiter mullock dump, 12700E 13100N, were compared with weathered material from the surface, in both hand specimen and thin section—thus permitting partial determination of the greenstone type.

A description of the relative positions of jaspilites and the thicknesses of the component units is now given.

Jupiter Jaspilite

Poverty Flat Formation:

Unit	Thickness Feet
10—Greenstone; dominantly chert-carbonate-chlorite schist, occasionally massive chert-carbonate-chlorite rock	14
9—Jaspilite	½
8—Greenstone, probably chert-carbonate-chlorite schist and massive chert-carbonate-chlorite rock	846
7—Jaspilite	½
6—Greenstone	40
5—Jaspilite	½
4—Greenstone	36
3—Jaspilite	½
2—Greenstone	95
1—Jaspilite	½
Estimated total thickness:	1033

Lennonville Beds

Geographic distribution.—The Poverty Flat Formation persists as the basal unit of the Boogardie Group throughout most of its extent. Variations in thickness were not measured.

Lithology.—The dominant greenstone type is a chert-carbonate-chlorite schist. In hand-specimen the unweathered rock is dark green but with abundant light-coloured irregular shreds of carbonate and chert. It weathers to a yellow-brown rock in which shreds of chert are still visible in a matrix of limonite. Bedding is weakly developed and rarely visible in surface outcrops. Schistosity is frequently well-developed close to quartz blows, and runs parallel to the dip and strike of the formation. Elsewhere the rock may appear massive.

Jupiter Jaspilite

Jupiter is the name of G.M.L. 1361^{M}. Mining operations on this lease were largely carried out in the Jupiter Jaspilite.

Definition.—The Jupiter Jaspilite is defined as that jaspilite with greenstone lenses which lies between the Poverty Flat Formation and the Mount Magnet Greenstone (see Fig. 2). The formation is typically developed on G.M.L. 136^{M} Jupiter, near the Jupiter mullock dump at 12780E 13160N.

The jaspilite consists of clear continuous black, brown and grey bands approximately 0.5 cm apart.

Good outcrop and the presence of numerous calcite nodules allowed ready recognition of the formation and accurate estimation of thickness along its length.

Geographic distribution.—The formation is well-developed in the area mapped. In the Hill 50 gold mine (414′ level) a four-foot jaspilite containing calcitic nodules is exposed in the main cross-cut and is thought to be the Jupiter Jaspilite. The formation has not been traced outside the limits of the area mapped in detail.

Petrography.—Two rock types are found in the Jupiter Jaspilite—these being greenstone and jaspilite. The greenstone outcrops on G.M.L. 1480^{M}. The outcrop of highly weathered rock is good and shows a marked, nearly vertical, fracture cleavage trending approximately north-east. The weathered outcrop is a medium yellow-brown colour without visible bedding. Its nature is indeterminate.

Mount Magnet Greenstone

Mount Magnet is the name of the township around which the Boogardie district mining operations now centre. It is situated 352 miles by road north-east of Perth.

Definition.—The Mount Magnet Greenstone is defined as that sequence of jaspilites and greenstones, including chloritized banded feldspar porphyry and quartz-carbonate-sericite-chlorite rock, lying between and bounded by the Jupiter Jaspilite and the Three Boys Formation.

The type section is on G.M.L. 1361^{M} Jupiter, between co-ordinates 12760E 13070N and 12130E 13000N. Outcrops of greenstone are poor, being

*Note: Co-ordinates shown thus: 13660E 11100N refer to surface co-ordinates expressed in feet. To obtain Hill 50 gold mine co-ordinates, expressed thus 13646E, 11075N, apply the transformation $E + 14 = E'$, $N + 25 = N'$, where E, N are mine co-ordinates and E′, N′ are surface co-ordinates.

highly weathered and lateritized. Jaspilites of this formation generally outcrop well, but because of large areas of poorly outcropping greenstones and the faulted nature of the type section, the indicated total thickness is approximate only.

The type section in stratigraphically descending order is given immediately below.

Three Boys Formation

Mount Magnet Greenstone:

Unit	Thickness Feet
9—Greenstone	360
8—Jaspilite	4
7—Greenstone	130
6—Jaspilite	2
5—Greenstone	44
4—Jaspilite	4
3—Greenstone	70
2—Jaspilite	1
1—Massive, fine-grained purplish-red, highly weathered greenstone	26
Estimated total thickness, Mount Magnet Greenstone	641

Jupiter Jaspilite

Geographic distribution.—The Mount Magnet Greenstone persists throughout the area mapped in detail. Unit 9 of the type section thins from a thickness of 500′ + in the south of the area to almost 140 feet at the junction of G.M.L.'s 1389M and 1435M. Thus the distinctive width of greenstone which marks the top of this formation in the south becomes less distinctive further north and the precise upper limit is more difficult to recognize.

On G.M.L. 1480M penecontemporaneous tectonics seem to be indicated in both this formation and the underlying Jupiter Jaspilite, by the presence of a buried hill-like structure, by the greenstone lenses appearing in the Jupiter Jaspilite and by intraformational folding suggestive of slumping. Should this evidence indicate tectonic instability, the rapid thickening and thinning of beds is readily explained as a broader consequence.

Facies variations.—Unit 9 varies in the manner indicated above. Jaspilite members of this formation are variable in both thickness and position. For example one jaspilite member changes in thickness from 4′ to 10′ between G.M.L. 1435M and G.M.L. 1480M. For this reason, certain correlation of individual jaspilite members from one fault block to the next is difficult.

Three Boys Formation

Three Boys is the name of G.M.L. 1322M, a lease about one half-mile south-east of the Hill 50 gold mine.

Definition.—The name Three Boys Formation is here proposed for the sequence of jaspilites and greenstones lying between and bounded by the Mount Magnet Greenstone and the Perseverance Jaspilite.

The type section is exposed west of the Hill 50 main shaft, between co-ordinates 11044E 12888N and 11350E 13000N on G.M.L. 1438M (Mars) and G.M.L. 1356M.

Because of the highly weathered nature of the fine-grained greenstone at the surface, no specimens were taken from the type locality. The lithologies described below are identified from the workings of the Hill 50 gold mine.

The following is a description of the type section in stratigraphically descending order.

Perseverance Jaspilite

Three Boys Formation:

Unit	Thickness Feet
14—Fine - grained plagioclase - magnetite - carbonate - quartz - chlorite - sericite schist and moderately massive fine-grained dark greenish grey, feldspar-bearing sericite-iron ore-carbonate-quartz-chlorite rock	40
13—Jaspilite	2
12—Quartz-magnetite-carbonate-chlorite schist	60
11—Jaspilite	2
10—Greenstone	30
9—Jaspilite	6
8—Greenstone	45
7—Jaspilite	3
6—Greenstone	13
5—Jaspilite	5
4—Greenstone	9
3—Jaspilite	1
2—Greenstone	85
1—Jaspilite	4
Total estimated thickness:	310

Mount Magnet Greenstone

Geographic distribution.—The Three Boys Formation persists throughout the area mapped in detail, and beyond to the south-east. To the north-west of the area the base of the Three Boys Formation is difficult to distinguish from the top of the Mount Magnet Greenstone.

Facies changes.—The thickness and position of the various units of this formation change in such a manner that their correlation from fault block to fault block is uncertain. Within the area mapped in detail the formation as a whole converges from 500′ thickness in the north-west to approximately 250′ thickness in the south-east. Over the lateral distance of half-a-mile of this convergence individual jaspilite members thicken as greenstone members become thinner.

Perseverance Jaspilite

Perseverance is the name of G.M.L. 1505M in which the main workings have been in the formation here defined as the Perseverance Jaspilite.

Definition.—The name Perseverance Jaspilite is proposed herein for that jaspilite lying between and bounded by the Three Boys Formation and the Mars Greenstone.

The type section is on G.M.L. 1438M (Mars) at co-ordinate 11116E 12744N. At this locality it is a banded brown, grey and black rock containing sparse cavities near its base, marking the position of leached or weathered calcitic nodules. It is thirty feet thick.

Geographic distribution and facies changes.—The Perseverance Jaspilite is readily recognizable throughout its length in the area mapped in detail and beyond to the south-east. Below is a Table showing variations in thickness of this formation within a lateral extent of three-quarters of a mile.

TABLE II

Locality	Thickness (feet)
G.M.L. 1287M	24
G.M.L. 1323M	40
G.M.L. 1282M	38
G.M.L. 1438M	30
G.M.L. 1435M	30
G.M.L. 1536M	26

Underground, the Perseverance Jaspilite may be seen in the Perseverance workings at a depth of 313′ and in the Hill 50 gold mine, 1,060′ level, at the east end of the new east crosscut.

Mars Greenstone

Mars is the name of G.M.L. 1438^{M}, a lease approximately 500 feet west of the Hill 50 main shaft.

Definition.—Mars Greenstone is the name given to the sequence of jaspilites and greenstones lying between and bounded by the Perseverance Jaspilite and the Hill 50 Jaspilite.

The type section is defined underground on the 313′ level of the Hill 50 gold mine and the Perseverance workings. However, due to poor structural data exposed in the underground workings, thicknesses of the strata are incompletely known and have been adopted from surface exposures near the south end of G.M.L. 1323^{M}.

The following is a description of the section in stratigraphically descending order.

Hill 50 Jaspilite

Mars Greenstone:

Unit	Thickness Feet
7—Magnetite- and quartz-bearing biotite-carbonate-chert-chlorite rock with distinct relict lamination and small-scale cross-lamination	10
6—Jaspilite	6
5—(?) Bedded, magnetite- and quartz-bearing, carbonate-chert-chlorite rock, fine-grained ilmenite-bearing plagioclase-quartz-chlorite rock, and (?) medium - grained chlorite - carbonate - albite rock	55
4—Jaspilite	8
3—Magnetite - carbonate - quartz - plagioclase-chlorite rock (20′ +), magnetite-bearing plagioclase-quartz-carbonate-chlorite schist, (?) ilmenite-plagioclase-chlorite rock and (?) ilmenite - bearing quartz - chloritized plagioclase-chlorite rock	112
2—Jaspilite	6
1—Fine-grained cherty quartz-plagioclase-chlorite rock	40
Total estimated thickness:	237

Perseverance Jaspilite

Distribution.—The Mars Greenstone may be traced through the area mapped in detail, and to the south-east; its extension to the north-west is not known. The stratigraphic sequence is broadly similar from G.M.L. 1287^{M}, through G.M.L. 1323^{M}, G.M.L. 1282^{M}, to G.M.L. 1438^{M}. On G.M.L.'s 1435^{M} and 1536^{M}, the formation boundaries may be traced, but, due to heavy lateritization and poor outcrop within the formation, little of the actual sequence is known.

Approximate local thicknesses of the formation are shown in Table III. They indicate convergence from south-east to north-west.

TABLE III

Locality	Thickness (feet)
G.M.L. 1287M	200
G.M.L. 1323M	230
G.M.L. 1438M	220-180
G.M.L. 1435M	240
G.M.L. 1536M	130

Hill 50 Jaspilite

Hill 50 is the name of G.M.L. 1282^{M}, on which the upper levels of the Hill 50 gold mine are situated. At the time of writing, ore shoots were being worked within the Hill 50 Jaspilite.

Definition.—Hill 50 Jaspilite is the name given to that jaspilite lying between and bounded by the Mars Greenstone and the Havelock Greenstone. The type section is exposed on the 613′ level of the Hill 50 gold mine, where a true thickness of 75′ is exposed.

Distribution and thickness variations.—The Hill 50 Jaspilite, because it is by far the thickest jaspilite in the Boogardie Group, serves as a useful marker bed. It may be traced from fault block to fault block in the area mapped in detail. Its extension, north-west and west of this area is not known, but it may be traced to the south-east for at least one mile.

Approximate thicknesses of the formation are shown in Table IV.

TABLE IV

Locality	Thickness (feet)
GM..L. 1287M	70
G.M.L. 1323M	77
G.M.L. 1282M	? 50-75
G.M.L. 1438M	65-80
G.M.L. 1536M	75 true width X-cut within the Hill 50 Central workings.

Havelock Greenstone

Havelock is the name of G.M.L. 1287^{M} on which this formation outcrops.

Definition.—Havelock Greenstone is the name given to the chloritized basalt and minor jaspilite lying between and bounded by the Hill 50 Jaspilite and the Saturn Formation.

The type section is exposed on the 313′ level of the Hill 50 gold mine at which location the formation is between 25′ and 30′ thick.

The following is a description of the type section.

Saturn Formation

Havelock Greenstone:

Unit	Thickness Feet
3—(Top) Jaspilite	$\frac{1}{3}$
2—Chloritized basalt	25-30
1—(Bottom) Chlorite schist	$\frac{1}{3}$
Total estimated thickness = approx.	30

Hill 50 Jaspilite

Distribution and thickness variations.—The Havelock Greenstone is traceable through G.M.L.'s 1462M, 1287M, 1323M, 1282M (subsurface) to G.M.L. 1438M. Its continuation on G.M.L. 1536M is obscured by extensive lateritization.

Approximate thicknesses for each locality are given in Table V.

TABLE V

Locality	Thickness (feet)
G.M.L. 1462M	22
GM..L. 1287M	24
G.M.L. 1323M	20
G.M.L. 1282M	30 (subsurface)
G.M.L. 1438M	19

Underground in the workings of the Hill 50 gold mine, the formation is exposed on all levels—its thickness reaches a maximum of 38′ on the 1304′ level.

Saturn Formation

Saturn is the name of G.M.L. 1457M. An open cut, known as the Saturn open cut, has been worked in the jaspilite members of this formation.

Definition.—Saturn Formation is the name proposed herein for that sequence of jaspilite and greenstone directly overlying the Havelock Greenstone, and bounded above by a considerable though unknown thickness of greenstone, apparently devoid of jaspilite members.

The type section lies between surface coordinates 10512E 11190N and 11230E 11130N. In the type section, the high degree of faulting and porphyry intrusion, coupled with a generally poor outcrop of both jaspilite and greenstone, render interpretations of the geology and thickness estimations inexact.

The figure given below (702′) is far less than that observed in other fault blocks, and must be accepted with reservations.

The following is a description of the section in stratigraphically descending order.

Saturn Formation:

Unit	Thickness Feet
14—Jaspilite	8
13—Greenstone	27
12—Jaspilite	20
11—Greenstone	6
10—Jaspilite	6
9—Greenstone	3
8—Jaspilite	27
7—Greenstone	68
6—Jaspilite	3
5—Greenstone	85
4—Jaspilite	5
3—Greenstone	94
2—Jaspilite	4
1—Greenstone	340
Total estimated thickness =	702

Havelock Greenstone

Geographic distribution and thickness variations.—The Saturn Formation may be traced from aerial photographs, throughout the entire examined length of the Boogardie Group. It appears to thin from approximately two thousand feet thickness, several miles south-east of Boogardie, to approximately seven hundred feet in the type section. Further north-west from Boogardie, it firstly thickens and then slowly thins until the junction with granite four miles west of the Hill 50 gold mine.

Thickness variations of individual members may be observed in units 8 to 14, which have thickened considerably on G.M.L. 1487M, (west of the Mars lease G.M.L. 1438M) from their thicknesses in the type area further south-east.

Lithology.—The typical rock type is a sericite-carbonate-chert-chlorite schist cut by innumerable carbonate-quartz veinlets which run subparallel to the foliation. On the 820′ and 1,060′ levels of the Hill 50 gold mine the unit is in part conglomeratic, especially near its base. One detrital fragment, about six inches in diameter, is roughly circular in cross-section and is composed of a white kaolin-like material regardless of being enclosed in unweathered schist on the 1,060′ level. Other fragments (e.g. of quartz) are smaller (about 0.5 inch in diameter) and roughly circular in cross-section. Clear, closely spaced bedding indicates a sedimentary origin for this rock. It weathers to a yellow-brown colour.

The lithologies of the overlying greenstone units are uncertain but are believed to include both schists containing variable amounts of quartz, biotite, sericite, chlorite and carbonate and a chloritized medium-grained porphyritic and trachytic rock composed dominantly of albite and chlorite with minor iron ore.

Petrology

Within the Boogardie Group, fine-grained sedimentary and igneous rocks and jaspilites occur in a conformable eugeosynclinal sequence. Metamorphism has so altered many of the rocks that their origin is indeterminate. Others are igneous in origin and probably lavas or sills; others are sedimentary in origin. Working with those rocks whose origin is least in doubt this section will deal with petrological features of the jaspilites and igneous and sedimentary greenstones which help to construct a picture of their depositional environment.

Flow Lavas

Units 1, 3, and 5 of the Mars Greenstone, the Havelock Greenstone, and parts (specimen 39515*) of the Mount Magnet Greenstone are probably flow lavas. They are generally massive and jointed and have suffered chloritization, sericitization and carbonation. Undoubted porphyritic texture is apparent in most specimens. The feldspars vary from albite Ab_{95} to oligoclase Ab_{73} indicating all stages of alteration from a more calcic plagioclase. The refractive indices of chlorite are constant at $1.622 \pm .002$ (6 specimens), identifying the variety as either diabantite or ripidolite.

Alteration of plagioclase to sericite, chlorite, quartz, carbonate, albite and rare epidote has taken place in many cases. These changes are

*Specimen numbers refer to specimens held at the University of Western Australia.

due to the instability of calcic plagioclase under greenschist facies metamorphism and in some cases are due to instability of the feldspar in the presence of alkaline hydrothermal solutions.

The data available suggest that the rocks were basic or intermediate lavas and/or sills such as basalt or andesite. These data are:—fine grain size; porphyritic texture; gradation of feldspars from albite to calcic oligoclase; relict basalt textures and general absence of normal crystalline quartz (microcrystalline quartz may be quite abundant). Anhedral quartz in these rocks may or may not be of primary origin. Where it is present it is not possible to ascribe acid or basic character to the original rock, even when a flow lava origin is admitted.

Sedimentary Greenstones

Sedimentary greenstone comprises much of the greenstone in the Poverty Flat Formation; unit 5 in the Mars Greenstone; unit 7 of the Mars Greenstone, and the base of unit 1 in the Saturn Formation.

All these rocks are fine-grained, with closely spaced bedding. The mineralogy is simple; microcrystalline quartz, carbonate, chlorite, sericite, magnetite, biotite and minor (?) detrital quartz in varying proportions. Plagioclase is absent.

Unit 7 of the Mars Greenstone has been studied in detail and the following sedimentary structures have been found:—

Well-developed closely spaced lamination (Fig. 3).

Small scale cross-lamination marked by fine-grained magnetite and biotite (Fig. 3).

Ripple markings and associated scour and fill structure (Fig. 4).

Small scale slumping.

In one locality an erratic of jaspilite about 18" in diameter.

In addition the following minerals have been found to be concentrated in certain laminae; calcite, biotite, magnetite, (?) detrital quartz, microcrystalline quartz, and chlorite. Of these, magnetite, biotite and possibly chlorite have

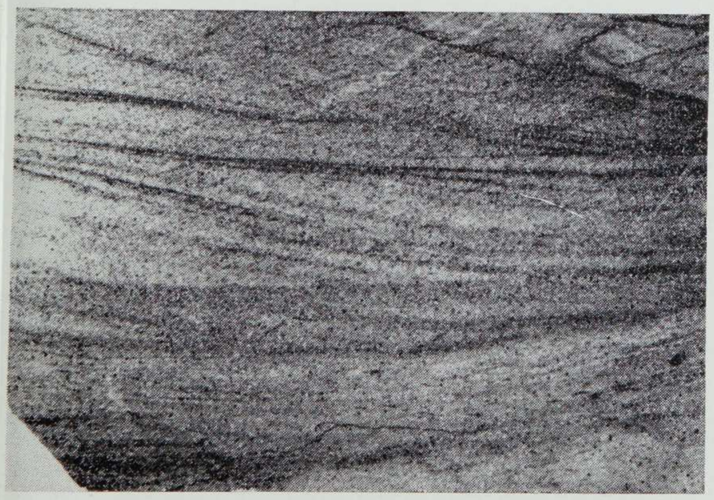

Fig. 3.—Cross-lamination in unit 7 of the Mars Greenstone (specimen 39544). Ordinary light X2.

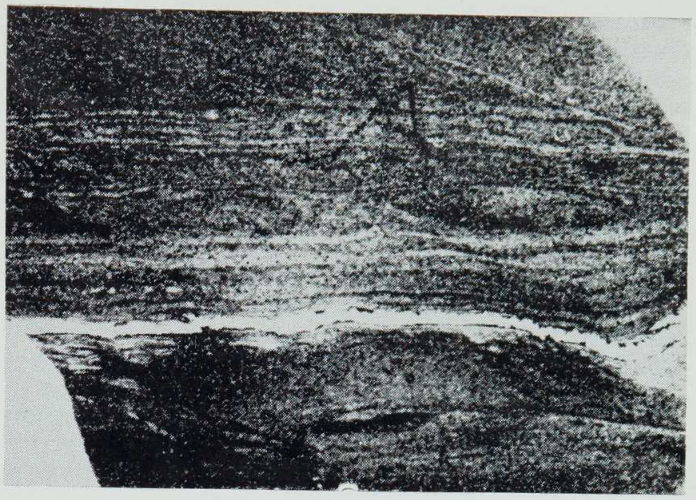

Fig. 4.—Ripple marking and associated scour and fill structure in unit 7 of the Mars Greenstone (specimen 39546). Ordinary light X2.

been derived from heavy minerals, originally sorted by physical processes. Carbonate, where concentrated in a single lamina appears to have been chemically precipitated although one specimen does show doubtful evidence of detrital origin for the carbonate. The intimate admixture of microcrystalline quartz and chlorite often with carbonate, indicates co-deposition. The chert and carbonate are believed to be largely chemical in origin while the chlorite is probably derived from pelitic detritus.

The rock resembles the result of a combination of slow chemical sedimentation of carbonate and (?) quartz, with additions of very fine terrestrial material, and fine volcanic ash; the latter probably altered during diagenesis to silica and clay minerals. Slight current action over a relatively flat depositional interface is indicated by small-scale cross lamination, ripple marks and associated scour and fill structures. This process and minor slumping would fill any major irregularities in the depositional interface and slumping appears to be the best explanation for the jaspilite erratic two feet from the base of the unit.

The presence of conglomeratic lenses in unit 1 of the Saturn Formation implies a shallow-water environment and this may be extrapolated to suggest a quiet shallow environment for the interbedded fine-grained sediments.

The deposition of the sedimentary greenstone was probably accompanied by contemporary vulcanism with the addition of ejectamenta (erratic boulder in unit 1 of the Saturn Formation) and by slumping due to seismic stimuli.

Jaspilite

Definition.—According to Holmes (1928, p. 127) jaspilite is "A term applied to rocks composed of interbanded layers respectively rich in silica (quartz or chalcedony) and iron oxides (magnetite, haematite, etc.). The chert-like bands have a red colour owing to the inclusion of flakes of haematite. Variable amounts of ferruginous amphiboles are generally present, and the rocks are not only conspicuously banded but are often contorted and brecciated."

Miles (1941, p. 15) suggests "that this term jaspilite might be extended slightly in meaning, to include certain black and white varieties of similar banded rock which, in many of the Western Australian goldfields, show close field relations with, and occasionally grade into, the red banded kind."

At depths of 600′ and greater the jaspilites of the Boogardie Group contain bedded calcite, often in an amount sufficient to designate a small specimen as a banded magnetite-calcite rock. Furthermore, under conditions of greenschist facies metamorphism, minor chlorite is developed rather than amphibole. Evidence is brought forward below to demonstrate that banded calcite-magnetite-chert rocks become silicified and oxidized at the surface to banded haematite and magnetite-chert rocks—true jaspilites under the definition.

Petrologic Description.—Specimen 39575 (11616E, 12433N, 613′ level) is a specimen of poorly auriferous jaspilite from the type locality of the Hill 50 Jaspilite.

In hand specimen it is a black and grey, clearly banded rock composed of alternating iron-rich, silica-rich, or carbonate-rich bands, 10 mm to 2 mm in width. Intraformational brecciation thought to be due to slumping, is evident in hand specimen. Minor sulphide mineralization occurs in small cross-cutting fractures and along favourable bands. The specimen has a specific gravity of 3.27.

In thin section the banding is seen to be prominent. Graded bedding or cross bedding is not present, although there is a variation in grain size of the microcrystalline quartz in different bands.

The carbonate, magnetite and quartz are bedded in a sedimentary manner. There is in this specimen and in all others examined from the underground workings a distinct tendency for the carbonate to occur in the same bands as magnetite. Minor fractures traverse the slide without any continuity or apparent displacement. They contain microcrystalline quartz where they cross chert bands and carbonate where they cross carbonate- and magnetite-rich bands, although no fracture was traceable from a chert band to a carbonate-rich band.

Constituent minerals are microcrystalline quartz (45%), iron ores (30%), carbonate (25%), and minor chlorite ($<1\%$).

Microcrystalline quartz is composed of anhedral grains 0.040 mm average size in coarser bands, down to 0.020 mm average size in finer grained bands.

Magnetite occurs as a dense cloud of fine or coarser particles arranged in thin laminae parallel to the bedding. The laminae may be so close as to form a single thick band of magnetite or may be as far as 0.25 mm apart. As a general rule, the further apart these laminae are the more microcrystalline quartz and the less calcite there is between them. Hence, closely spaced thick bands of iron ore contain abundant interlaminated calcite. The grain size of the magnetite is variable, thick bands containing the coarsest magnetite; thin bands in quartz resemble trails of dust when seen under the microscope. On the average the magnetite is of slightly smaller size than the associated microcrystalline quartz.

Pyrite and minor pyrrhotite are found near the edges of the iron- and carbonate-rich bands, associated with a slightly coarser grained (recrystallized) quartz. They occur as irregular crystals of varying grain size, generally much larger than associated magnetite.

The association of pyrite in bands of magnetite and carbonate with a coarser grained quartz suggests that some of this coarser grained quartz has originated by metasomatic replacement of carbonate.

The variation in grain size of the microcrystalline quartz is most likely not primary, but is controlled by either recrystallization or secondary introduction.

Chlorite is associated with pyrite and coarser grained microcrystalline quartz.

The microscopic characters of other jaspilites, or of other specimens in the same formation, do not differ essentially from those above excepting:

(1) where the jaspilite has suffered metasomatism in the ore shoots of the Hill 50 gold mine;

(2) where the jaspilite has suffered metasomatism causing the development of actinolitic amphibole;

(3) where the jaspilite has suffered metamorphism adjacent to the granite;

(4) where the jaspilite outcrops at the surface, extending to an unknown depth, possibly hundreds of feet. Silicification of the carbonate in the jaspilite yields a banded microcrystalline quartz-iron ore rock.

Metasomatic changes in ore shoots.—39576 (11610E, 12905N, 820′ level) is ore known at the mine as massive pyrrhotite. It is a heavy, metallic-lustred, bronze-yellow rock with a faint relict banding. Specific gravity = 3.86.

In thin section the rock appears massive and is composed dominantly of pyrrhotite and minor pyrite (45%), quartz (30%), and carbonate (25%). Extensive recrystallization has taken place in this rock, quartz occurring in all sizes from that of a normal jaspilite to 0.2 mm across. Calcite and pyrrhotite also occur in larger grains, averaging about 0.1 mm across.

It is concluded that metasomatic replacement of magnetite by pyrrhotite and minor pyrite has taken place. Most of the magnetite and carbonate was concentrated into bands before ore formation. The process of metasomatism has attacked these bands. Magnetite was replaced by sulphides and the carbonate recrystallized. Depending on the intensity of the metasomatism, the associated microcrystalline quartz was either poorly recrystallized for a short distance on either side of these iron- and carbonate-rich bands, or experienced all stages of recrystallization.

A. B. Edwards (1955, p. 35) reported: "The opaque minerals observed in the ore are magnetite and a trace of ilmenite, which are components of the jaspilite rock forming the "host" rock of the mineralization and were not introduced by the mineralization, and pyrite, pyrrhotite, chalcopyrite, (?) galena and gold. The gangue introduced by the mineralization comprises quartz and a carbonate mineral." He concludes the "although the gold shows a distinct preference for association with quartz it is genetically related to the sulphides. This is apparent from the occurrence of occasional "veinlets" of gold, about 0.50 mm × 0.005 mm, forming parts of pyrrhotite veinlets.

It is apparent also from the consistent association of the gold with areas in which sulphides are present, and its almost complete absence from areas lacking sulphides."

Surface silicification of jaspilites.—The evidence of surface silicification is:

(a) At depth, the jaspilites contain abundant carbonate, while at the surface they contain only traces of carbonate.

(b) At depth, the Perseverance Jaspilite and the (?) Jupiter Jaspilite contain primary nodules of calcite which are overlain directly by a band of calcite (approximately ¼″ to ½″ thick). Whereas, at the surface these nodules are represented mainly by cavities in several cases, as in specimen 39514, they are composed of coarser microcrystalline quartz. Overlying these nodules at the surface is a band of microcrystalline quartz.

The depth to which the silicification extends is not known. Jaspilite on the 313′ level appears to be highly siliceous in hand specimen while jaspilite from the 613′ level downwards contains a high percentage of carbonate. In particular, one specimen is composed almost entirely of bedded carbonate and magnetite crossed by a vein of coarser microcrystalline quartz. The Hill 50 Jaspilite on the 1304′ level appears to have a higher percentage of carbonate than at higher levels.

Within the quartz of the nodules of the Jupiter Jaspilite there are particularly numerous and often large inclusions of carbonate. The microcrystalline quartz in the body of the rock contains inclusions of carbonate of a much smaller size. These are harder to detect and their abundance is difficult to estimate.

Every thin section of jaspilite examined from the area, even underground on the 820′ and 1060′ levels, contained inclusions of carbonate of varying, generally minute size, in microcrystalline quartz. If these indicate silica replacement of carbonate, then a very large portion of each jaspilite must once have been composed of carbonate.

Surface silicification of jaspilites may be taken as proven. The silica in these jaspilites below the zone of surface silicification may have originated by metasomatic replacement of strata previously richer in carbonate. However, no valid criteria have been found to prove this hypothesis.

Environment of Deposition of the Boogardie Group

The great thicknesses of sediments, isoclinal folding and granite intrusion as in the Mount Magnet Greenstone belt are typical of orthogeosynclinal sequences. The lithologies in the Boogardie Group (flow lavas, bedded chemical and pelitic sediments and pure chemical sediments (jaspilites)) are characteristic of the eugeosynclinal suite of Kay (1951). Furthermore, tectonic instability is implied by the marked convergence of formations and members, by a buried hill structure and by slumping.

The provenance of the detritus is probably from within the eugeosyncline itself, rather than from without. That is, the clastic material (and some of the chemical) is primarily volcanic ejectamenta which has passed through the modifying influences of the normal processes of clastic and chemical sedimentation before deposition. No orthoquartzite, greywacke or arkose is intercalated in the section and the sequence cannot be ideally equated with the tectonic cycle of Krynine (1943, Fig. 1, p. 3).

The presence of small-scale cross lamination, ripple marking and scour-and-fill structures in the Boogardie Group is indicative of shallow-water depositional environments.

Structure

The eugeosyncline has been recognized as a wide, probably elongate, subsiding belt in which volcanic activity is dominant. Flow lavas and volcanic sediments form part of the geosynclinal filling. When they accumulated more rapidly than subsidence could accommodate them, volcanic islands were formed, contributed pelitic material to the geosyncline and then sank below sea-level, once subsidence overcame accumulation. As a consequence of sloping sea floors, members and formations were thickened or thinned and slumping of unlithified material occurred. Characteristically, the sediments of an eugeosyncline next become buried and suffer load metamorphism, isoclinal folding, faulting, intrusion by granite and metamorphism. The structures within the Boogardie Group described below are such that they could logically be explained by the above type of environment.

Primary Structures within the Boogardie Group

The following primary structures have been recognized within the Boogardie Group: buried valley structure; buried hill structure; calcareous nodules; ripple marking and associated scour and fill structure; cross lamination; thickening and thinning of units; slump structures and brecciation.

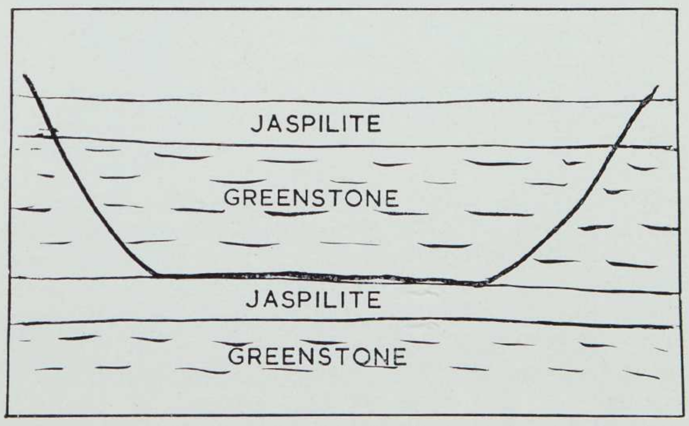

Fig. 5.—Initial stages in the development of a buried-valley structure showing the cutting of a channel.

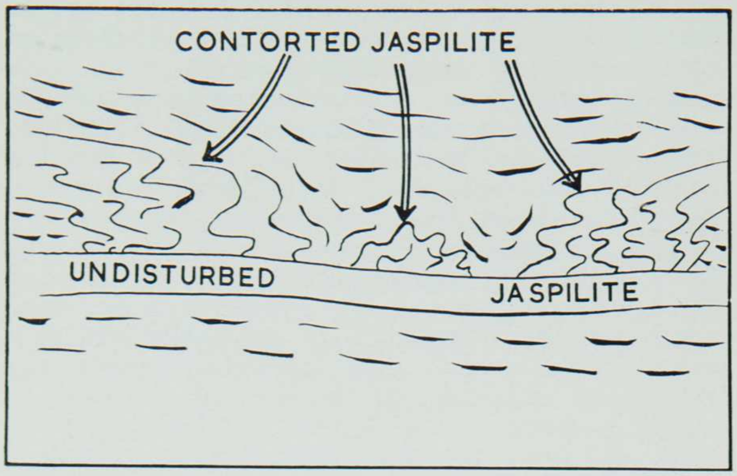

Fig. 6.—Final stage in the development of a buried-valley structure showing diagrammatically the way in which the upper jaspilite has slumped down onto the lower jaspilite, followed by burial.

Buried valley structure.—This structure is developed at 10880E, 14420N. Figs. 5 and 6 illustrate diagrammatically how the structure shown at this locality is thought to have developed. Initially, it is believed the two jaspilite members were conformably interbedded with greenstone (Fig. 5) and that subsequently a valley structure was developed by either slumping or scouring. Fig. 6 illustrates the manner in which the upper jaspilite member has slumped into the valley so formed, the whole being covered with later deposits of sediments.

Buried hill structure.—This structure has been mapped at 10120E, 14500N. Fig. 7A, B, C, D and Figure 8 illustrate diagrammatically how the structure at this locality is thought to have developed. Tectonism contemporaneous with sedimentation has been the cause of both thickness variations of the members and large-scale and small-scale slumping.

Calcareous nodules.—The Perseverance Jaspilite and the Jupiter Jaspilite contain small calcareous nodules. Fig. 9 is a thin section across a nodule in specimen 39585 from the Perseverance Jaspilite (1060′ level of the Hill 50 gold mine). Laminae of chert, carbonate and magnetite underlying the nodule have been squeezed out in a compression fold. Overlying the nodule there is a band of carbonate and iron ore in which cross-bedding and gravity differentiation of the minerals may be seen. Above this latter band are laminae of chert, carbonate and magnetite. The author believes that the nodule grew by a process of chemical accretion upon the depositional interface and that the weight of the nodule was sufficient to depress the laminae beneath it, adjustment being a compression fold in a lateral direction. The growth of the nodule was halted by the coagulation in the overlying waters of carbonate and iron ore. These were precipitated and the iron ore (by reason of its higher specific gravity) became separated from the carbonate. On reaching the depositional interface the first of the carbonate and magnetite to arrive was cross-bedded off the side of the protuding nodules (supratenously). Subsequent precipitation smoothed the new depositional interface.

Ripple marking and associated scour and fill structure.—Ripple marking has been found in unit 7 of the Mars Greenstone (specimen 39546) (see Fig. 4). The cross lamination of the ripple ridges and the collection of magnetite grains in the deepest part of the trough serves to distinguish these structures from the fill structures in the ripple valleys (Shrock 1948, p. 104). The fill structures possess cross-lamination in which the foreset laminae are asymptotic with one slope and are sharply truncated on the other slope. Magnetite and biotite are distributed at the base of the foreset laminae.

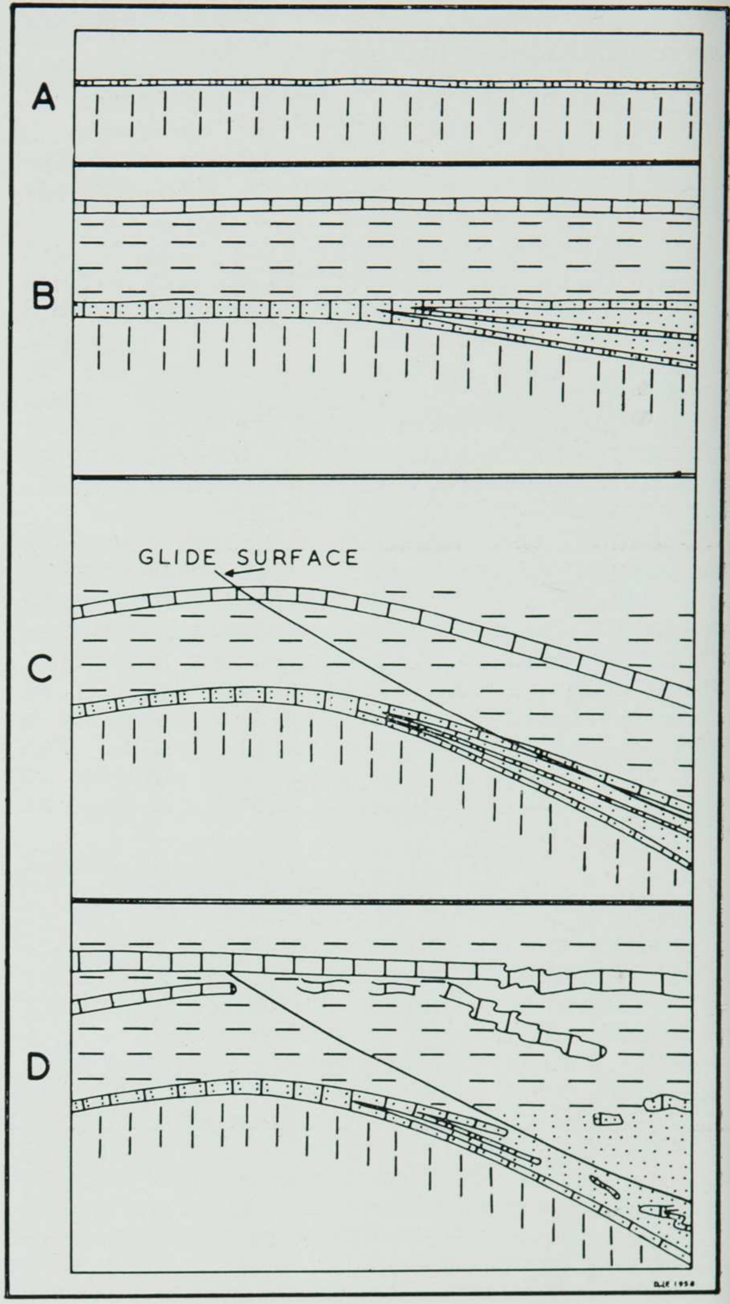

Fig. 7.—Initial stages in development of buried hill structure at 10120E, 14500N.

A. Deposition of the Poverty Flat Formation and portion of the Jupiter Jaspilite.
B. Monoclinal warping during deposition of the remainder of the Jupiter Jaspilite and subsequent deposition of the first two units of the Mount Magnet Greenstone.
C. Repetition of the warping to produce a hill structure. Slumping commenced due to steepening of depositional dip.
D. Normal sedimentation established over the slumped sediments, unit 3 of the Mount Magnet Greenstone was laid down on a slightly sloping sea floor and subsequently slumped.

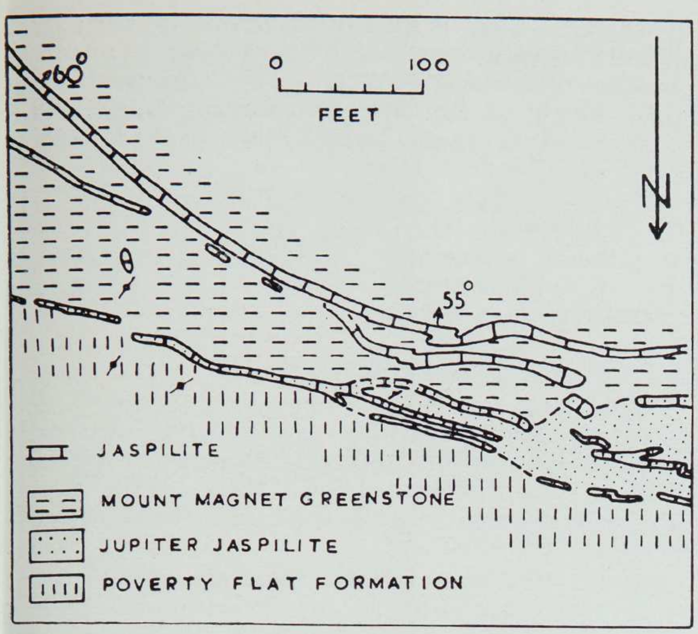

Fig. 8.—The buried hill structure as mapped after regional tectonic deformation has been superimposed on the initial structure.

Cross lamination.—Small scale cross lamination is developed within unit 7 of the Mars Greenstone.

Thickening and thinning of units.—The rapid thickening and thinning of formations and members has been demonstrated earlier in the section dealing with the stratigraphy of the Boogardie Group.

Slump structures and brecciation.—The differentiation of slump structures and tectonic structures depends upon criteria related to the different modes of origin of the two features. The following criteria have been used where possible to determine the origin of contortions in the jaspilites:—

(1) A highly puckered contortion of small amplitude, contained within relatively undisturbed beds, suggests gravity slumping.

(2) Broad folds of large amplitude, repeated in the underlying and overlying strata indicate tectonic folding.

(3) A distinct or probable lineation running parallel to the axis of a fold or series of folds is evidence for tectonic drag folding, except in the limiting case where the impressed lineation coincides with the axes of true slump folds.

(4) Strata are considered to be slumped where the folded beds are overlain by a local unconformity.

(5) Slump folds are overturned towards the depression whereas tectonic folds are overturned towards the anticlines.

Many of the incompetent folds in the Boogardie Group are indeterminate in origin. Slumping requires a suitable unlithified state of the sediment and either an initial slope of the depositional interface or an external source of energy such as could be provided by outpourings of basic lava. These conditions are thought to have existed during the deposition of many of the jaspilites.

Slumping has been used above to indicate top and bottom. Another use is to be found in the correlation of jaspilite members. Slumping being a primary feature could be typical of certain units. Attention to slump features during mapping might enable the correlation of sporadic outcrops and of strata on each side of fault blocks.

Tectonic Structures

The tectonic structures are folds, faults and joints which have developed after deposition and compaction of the sediments.

Folds.—Two types of folds have been recognized, namely regional folds and drag-folds.

Fig. 1 illustrates the regional structure. The Boogardie Group and the Lennonville Beds are folded into a tight, southerly plunging, inclined syncline which has characteristics as follows:—

(1) The axial plane trends 207° (S.S.W.).

(2) The west limb of the syncline strikes approximately 225° (S.W.) and dips approximately 60° E.

(3) The east limb of the syncline strikes approximately 150° (S.E.) and dips between 75° E. and 75° W.

(4) The lineation in hornblende schists adjacent to the granite on the western limb plunges 40°-65° S. in the direction 155° to 190° (S.E.-S.).

The folding has been interpreted as the result of granite intrusion (see General Stratigraphy).

Drag-folds related to larger fold structures are recognizable where they are not disharmonic. The typical example is on the 313′ level of the Hill 50 gold mine at (11623E, 12180N). At this locality the junction between the Saturn Formation and the underlying Havelock Greenstone is drag-folded. The north-plunging drag-fold is related to the main north-plunging anticlinal drag-fold of the mine at that level. The 'Main Oreshoot' of the Hill 50 gold mine is structurally controlled by a drag-fold (probably related to the 'Boogardie Break' system) and there are numerous disharmonic folds which are unreliable for structural interpretation.

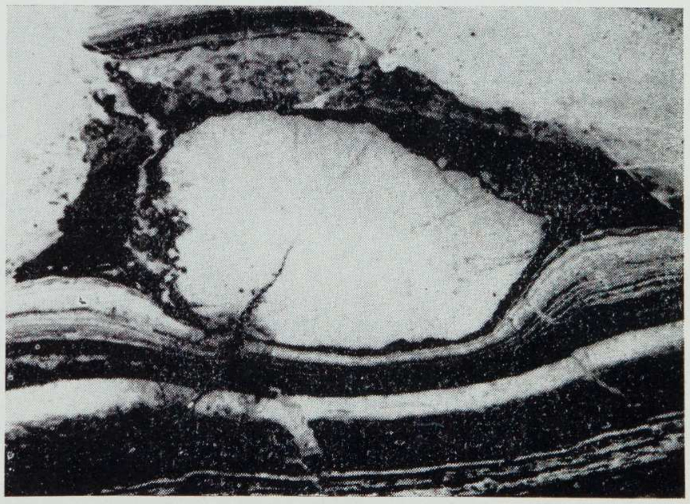

Fig. 9.—Thin section of a calcite nodule in the Perseverance Jaspilite. Ordinary light X2.

Drag of strata against faults is widespread in the Boogardie District. The direction of the drag indicates the direction of the movement. The large east-west fault which cuts the north-west corner of the area shows a fine example of drag adjacent to faults.

Faults.—The Boogardie Group is traversed by many faults and the most complex faulting is found in the vicinity of the Hill 50 gold mine. The faulting is believed to have developed during a late stage of regional folding prior to the consolidation of granite because the fault surfaces are not folded and the granite-greenstone contact appears unfaulted.

Three major faults trend sub-parallel to the major synclinal axis, the Hill 50 Fault being typical with a throw of approximately 600 feet. Two of these faults are sinistral, the other dextral.

Two later shears cut this system of faults. One cuts the north-west corner of the area in an east-west direction, and the other is the Main Fault of the Hill 50 gold mine which runs in a north-south direction. They are believed to be the result of thrusting on each flank of the syncline downwards towards its nose.

The 'Boogardie Breaks' are faults of minor throw which trend sub-parallel to the Hill 50 Fault (N.E.). The 'Breaks' are exposed on 414′ level of the Hill 50 gold mine where a number of them form the channels of porphyry intrusion. Their movement is dominantly dextral both on the 414′ level and to the south of this level. North of the 414′ level their movements are both dextral and sinistral. These faults are not folded against the Main Fault and they do not appear to cross or displace the Main Fault. For this reason they are probably complementary faults. Movement along the Main Fault may have arched the sediments on either side and the relief of this arching was marked by a tensional shattering and porphyry intrusion along the tensional faults, the 'Boogardie Breaks', and along tensional sections of the Main Fault.

The porphyries are cut by a system of flat-dipping reverse faults, striking parallel to and antithetic towards the Main Fault.

On the 313′ level of the Perseverance workings the 'Boogardie Breaks' are cut by a flat-dipping fault, parallel in strike to the strike of the flat-dipping faults above but dipping in the opposite direction. This strike fault is cut in turn by a steeply dipping transverse fault, striking approximately 290° (W.N.W.). On the 820′ and 1060′ levels of the Hill 50 gold mine there is a dolerite-filled fault parallel to the transverse fault on the 313′ level.

Joints.—Joints are well-developed in the Hill 50 Jaspilite on the Mars lease, G.M.L. 1438M; in several porphyries underground and within the Mars Greenstone in the 313′ level of the Perseverance workings.

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